Global HYCOM and Advanced Data Assimilation

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LONG-TERM GOALS

The long-term goal is to use a HYbrid Coordinate Ocean Model (HYCOM) with data assimilation in an eddy-resolving, fully global ocean prediction system with transition to the Naval Oceanographic Office (NAVO) at .08° equatorial resolution in 2006 and with .04° resolution by the end of the decade. Equatorial resolution of .08° (.04°) increases from 9 km (4.4 km) at the equator to 6 km (3 km) at 47° latitude. The Arctic is covered by a bipolar "PanAm" grid. At 59°N it matches the spherical grid covering the rest of the global ocean. The model will include shallow water to a minimum depth of 10-20 m and will provide boundary conditions to finer resolution coastal models that may use HYCOM or a different ocean model.

OBJECTIVES

Exploratory development and evaluation of HYCOM as a data-assimilative next generation model with generalized coordinates (hybrid isopycnal/terrain-following (σ)/z) and application of this model to eddy-resolving global ocean prediction. First use the Pacific north of 20°S, the Japan/East Sea (JES) and the Intra-Americas Sea (IAS) as test beds for modeling, grid nesting and/or a hierarchy of data assimilation schemes from relatively simple to advanced.

APPROACH

This project is highly collaborative with 5 other projects (see Related Projects). These projects focus on other aspects of the research such as ocean dynamics, most aspects of model development, other model domains and other data assimilation techniques.

HYCOM is designed as a generalized (hybrid isopycnal/σ/z) coordinate ocean model. It is isopycnal in the open stratified ocean, but reverts to a terrain-following coordinate in shallow coastal regions, and to z-level coordinates near the surface in the mixed layer. This generalized vertical coordinate approach is dynamic in space and time via the layered continuity equation, which allows a dynamical transition between the coordinate types. Like MICOM, HYCOM permits isopycnals intersecting sloping topography by allowing zero thickness layers. HYCOM was developed from MICOM using the theoretical foundation for implementing a hybrid coordinate system set forth in Bleck and Boudra (1981) and Bleck and Benjamin (1993).

HYCOM development is a close collaboration between Los Alamos National Laboratory (Rainer Bleck), NRL (Alan Wallcraft) and the University of Miami (George Halliwell), where the person in

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parenthesis is the lead performer in each group. Alan Wallcraft is in charge of developing and maintaining the standard version of the model, one that is scalable and portable and can run on the latest computer architectures. The HYCOM/NOPP project has the lead on basic model development and a Common HPC Software Support Initiative (CHSSI) project has the lead on scalability and portability of the computer code. Model grid nesting (in collaboration with U. Miami) is the main contribution of this project to model development. HYCOM will be maintained as a single source code with maximum feasible backward compatibility. The source code and documentation will be developed to the standard for a Navy operational product and for a community ocean model.

Initially, NRL work on the global domain will be at relatively coarse resolution (.72° then .24° at the equator) under the HYCOM/NOPP project in close collaboration with Rainer Bleck (LANL) and Eric Chassignet (U. Miami). This project will begin a major role in FY04 when the global model becomes eddy resolving with an increase to .08° equatorial (~7 km mid-latitude) resolution. During FY01-FY04 this project will work on development and evaluation of a HYCOM Pacific model with up to .08° equatorial resolution and Joe Metzger (NRL) taking the lead. The .08° HYCOM Pacific modeling will use computer time from an approved FY02-04 DoD High Performance Computing (HPC) Challenge grant (Eric Chassignet lead PI). A comparable effort is underway for the Atlantic as part of the HYCOM/NOPP project (see separate ONR reports).

The IAS domain circumscribes the Caribbean, Gulf of Mexico and Bahamas region. Tamara Townsend (NRL) has the lead on IAS modeling which is included (1) for the nesting effort, (2) for the opportunity to perform numerous simulations at .08° resolution, even a few at .04°, and (3) as a high resolution test bed for advanced data assimilation techniques. The HYCOM JES modeling is primarily the domain of other related projects. It is included here only as needed to support the data assimilation effort. The JES is smaller than the IAS and has a distinctly different mid-latitude dynamical regime (Hogan and Hurlburt, 2000) that is more relevant to the Gulf Stream (Hurlburt and Hogan, 2000) and the Kuroshio (Hurlburt et al., 1996) and is thus an excellent high resolution test bed for advanced data assimilation. Pat Hogan (NRL) is the JES modeler for this project.

The main participants in the project data assimilation effort are Gregg Jacobs (NRL), Hans Ngodock (associate researcher at U. Southern Mississippi and former postdoc of Andrew Bennett) and Ole Martin Smedstad (PSI). The main non-project collaborators are Remy Baraille (SHOM contractor in France), Geir Evensen (Nansen Center in Norway) and Carlisle Thacker (NOAA/AOML). Ole Martin will take the lead in implementing baseline data assimilation techniques. The baseline techniques will be used in comparison to more advanced techniques for efficiency and accuracy. Gregg and Hans plan to work on HYCOM data assimilation using (1) the 4DVAR representer method with an adjoint to be provided by Remy Baraille and (2) ensemble Kalman filtering, the latter in collaboration with Geir Evensen. Complete altimeter data sets from TOPEX/POSEIDON, ERS-2, GFO, JASON-1, and ENVISAT with additional corrections will be available up to real time; similarly for MCSSTs. In addition, 1/8° mesoscale depicting MODAS analyses of sea surface height (SSH) and sea surface temperature (SST) with estimated error fields will be available. The data assimilative model results will be compared with unassimilated data enumerated in the HYCOM/NOPP ONR report. Both sets will be used in model evaluation.

WORK COMPLETED

Under collaborative HYCOM projects Alan Wallcraft completed development of HYCOM 2.0 with 2-level parallelization, MPI and OpenMP, and FORTRAN 90 coding style. It was released for general use on 3 July 2001. The mixed layer options are KPP (Large et al., 1997) and Kraus-Turner.

Joe Metzger is using HYCOM to model the Pacific Ocean north of 20°S, including the marginal seas. He has run several .32° climatologically-forced 10 year simulations, including a HYCOM vs MICOM mode comparison. In August 2001, he ran a .16° simulation (~14 km resolution at mid-latitudes) for 5 years in about a month. Resolution over this domain will be increased to .08° at the equator for simulations performed under an approved FY02-04 DoD HPC Challenge project, but only a few years are planned in FY02.

In collaboration with U. Miami, Alan Wallcraft developed a one-way nesting capability for HYCOM. Alan and Tamara Townsend have successfully tested it using the .08° HYCOM IAS model with boundary conditions from the .32° HYCOM Atlantic model run by the HYCOM/NOPP project (see separate ONR report). Nested IAS simulations have been run up to a year as illustrated in the figure.

Under the HYCOM/NOPP project Pat Hogan (NRL) prepared a tar file with HYCOM 2.0 bundled with everything to continue one of his .32° Atlantic simulations and use it in data assimilation and testing. This file was provided to Remy Baraille in France and other HYCOM users. Remy is working on components needed for the HYCOM data assimilation effort in this project. He has already implemented the Cooper and Haines (1996) technique which Ole Martin Smedstad needs for downward projection of SSH from altimeter data. He has provided it to Ole Martin and is now working on a parallelized tangent linear adjoint for HYCOM, which is needed for the 4DVAR representer method that Gregg Jacobs and Hans Ngodock plan to use in this project. Remy estimates that the adjoint will be ready for general use by mid 2002. In the meantime Gregg and Hans plan to collaborate with Geir Evensen on ensemble Kalman filtering data assimilation, which does not use an adjoint. Hans visited both Remy and Geir and acquired Remy's existing adjoint for MICOM and the ensemble Kalman filter code from Geir. Gregg, Hans and Ole Martin plan to use the JES domain as their initial test bed for data assimilation in this project. Pat Hogan has completed several JES simulations at 1/8°, 1/16° and 1/32° resolution mostly under a separate ONR project (see related projects and a separate Hurlburt and Hogan ONR report).

RESULTS

With the release of version 2.0 via collaborative projects, HYCOM has reached the maturity required for broad application. It is scalable up to O(1000 cpus) via two levels of parallelization, either or both of which can be used, and it can run on computing platforms ranging from PCs to a variety of supercomputers with different parallel architectures. This was accomplished using a single source code for all machine types.

Since Joe Metzger was able to run a .16° HYCOM Pacific simulation for 5 years in a month, this domain and resolution are suitable for multiple simulations with different model parameters and atmospheric forcing products and for experiments with 6 hourly interannual atmospheric forcing 1979-2001. As expected, higher resolution is needed for sufficient inertial flow and eddy kinetic energy in the Kuroshio extension east of about 155°E.

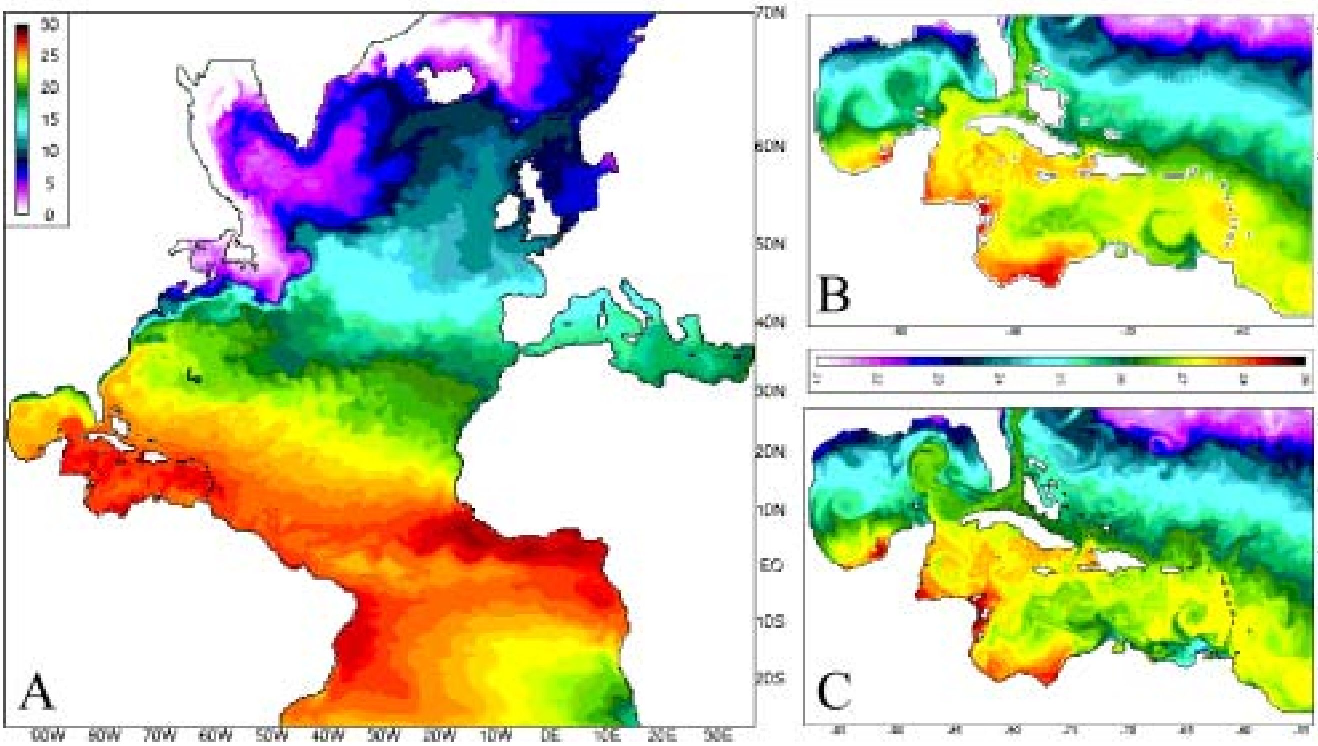

Figure caption. (A) Full domain January snapshot of sea surface temperature (SST) from 0.32° Atlantic HYCOM. (B) May snapshot of SST in the Intra-Americas Sea (IAS) region of the same model shown in (A). (C) Corresponding SST snapshot from the nested 0.08° IAS HYCOM. Both models used atmospheric forcing from a 1979-1993 monthly mean ECMWF climatology. The Atlantic basin HYCOM is relaxed to the 1/8° MODAS climatology at the open boundaries to include the global thermohaline circulation. This model was used to update the open northern and eastern boundaries of the IAS model (C) with barotropic information daily and 3-D structure every 6 days.

In the nested IAS domain, boundary conditions are taken from standard archive files for the enclosing Atlantic domain. Thus, the enclosing simulation does not need to be rerun to support a new nested domain. The IAS domain has a large open boundary including a corner. This makes it a good test bed for a HYCOM nested grid capability. Comparison of the .08° IAS and the .32° Atlantic model results over the Caribbean shows the strong impact of the resolution increase on the eddy activity, as illustrated in the figure. There are also some negative impacts of the coarse resolution simulation on the nested fine resolution model. The Atlantic model must have sufficient resolution to provide adequate boundary conditions for the IAS model.

HYCOM development had to reach a sufficient state of maturity before the HYCOM data assimilation effort could begin in earnest. That occurred with the release of HYCOM 2.0 on 3 July 2001. With the downward projection component from Remy Baraille, Ole Martin has everything needed to develop a baseline HYCOM data assimilation capability for satellite altimeter data. The OI analysis capability for the altimeter data is already in place and Ole Martin has developed several alternatives for mean SSH to add to the altimetric deviations in the Atlantic, IAS and JES domains. In cases where a model mean

was used, a rubber sheeting technique was used to reduce any current pathway errors. Future improvements in these means are anticipated as the modeling and data assimilation efforts proceed.

The Cooper-Haines technique for downward projection of SSH has been used in MICOM and is the first downward projection technique that will be used and evaluated in HYCOM. Later, Ole Martin will try the statistical inference technique in Hurlburt et al. (1990), which is used in the NRL Layered Ocean Model (NLOM) as well as synthetic temperature and salinity profiles derived from SSH and SST using MODAS statistics based on historical hydrographic data. MVOI (Jim Cummings, NRL) and an adaptive filter (Remy Baraille) are also candidate techniques. Carlisle Thacker's group has been working on assimilation of temperature profile data into HYCOM as part of the HYCOM/NOPP project. Ole Martin has been in contact with Carlisle's group. They plan to collaborate on implementing a scheme which assimilates both measured and synthetic temperature and salinity profiles. Using the JES domain as a test bed, the baseline data assimilation schemes used by Ole Martin will be compared for efficiency and accuracy with 4DVAR representer method and ensemble Kalman filter results of Gregg Jacobs, Hans Ngodock and collaborators.

IMPACT/APPLICATIONS

HYCOM with data assimilation is planned for use in a fully-global, eddy-resolving global ocean prediction system as noted under LONG-TERM GOALS. It will provide boundary conditions to finer resolution coastal models which may use HYCOM or a different ocean model. HYCOM is designed to make optimal use of three types of vertical coordinate, isopycnal, σ and z-level. Isopycnals are the natural coordinate in stratified deep water, terrain-following (σ) coordinates in shallow water and z-levels within the mixed layer. The layered continuity equation allows a dynamical space and time varying transition between the three coordinate types. HYCOM also permits isopycnals intersecting sloping topography by allowing zero thickness layers. Therefore, it should allow accurate transition between deep and shallow water, historically a very difficult problem for ocean models. It also allows high vertical resolution where it is most needed, over the shelf and in the mixed layer. The isopycnal coordinate reduces the need for high vertical resolution in deep water. The lead PI is a member of the U.S. and International Steering Teams for the Global Ocean Data Assimilation Experiment (GODAE), a multinational project designed to help justify a permanent global ocean observing system by demonstrating useful near real-time global ocean products.

TRANSITIONS

The 6.2 project preceding this one lead to the transition (via 6.4) of the first eddy-resolving nearly global ocean prediction system to NAVO, where it is now an operational product. It uses NLOM with 1/16° or ~7 km mid-latitude resolution and 7 layers in the vertical, including a bulk mixed layer. It excludes the Arctic and most shallow regions. Real-time results from this system can be seen at the web site http://www7300.nrlssc.navy.mil/global_nlom.

RELATED PROJECTS

The multi-institutional NOPP project HYCOM Consortium for Data-assimilative Ocean Modeling (see separate ONR reports), a 6.1 ONR JES DRI project (see separate ONR report), 6.1 EPIC, 6.1 Thermodynamic and Topographic Forcing in Global Ocean Models, 6.3 High Fidelity Simulation of Littoral Environments (CHSSI) and 6.4 ADFC Support. Additionally, the project receives grants of

HPC time from the DoD High Performance Computing Modernization Office. The lead PI is a member of both the International and U.S. GODAE Steering Teams.

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